Chemical Aid for Shucking the Pacific Oyster, *Crassostrea gigas*

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CONTENTS

Abstract iv

Resume v

Introduction 1

Material and Methods 2

Results and Discussion 6

Acknowledgments 12

References 13

Tables 14

Figures 28

Appendices 31

ABSTRACT

Whyte, J.N.C. and B.L. Carswell. 1983. Chemical aid for shucking the Pacific oyster, Crassostrea gigas. Can. Tech. Rep. Fish. Aquat. Sci. 1238: v + 33 p.

Magnesium salts proved to be the only chemicals examined capable of gaping oysters to aid the shucking process. Incidence of gaping, optimal in 0.327M aqueous magnesium chloride, was unaffected by temperature but was dependent on dry storage of the oyster prior to immersion. Inclusion of magnesium from aqueous magnesium chloride plateaued at approximately 0.3% wet weight of oyster meat after 12 hours of exposure yet was completely reversible in vivo within 24 hours of reimmersion in seawater. Sodium, potassium and calcium were the major elements displaced from oysters by treatment with magnesium chloride. Infusion of magnesium with displacement of calcium was considered responsible for the inhibition of muscle contraction and consequent gaping of the oyster. At a commercial shucking operation magnesium chloride treatment was 80+% effective in gaping test oysters and significant productivity gains from increased ease of shucking was demonstrated, particularly for clustered oysters. Magnesium levels declined in meat shucked and packaged in a commercial manner. Brine treatment was more effective than fresh-water leaching in removal of infused magnesium and retention of constituent carbohydrate in oyster meat. Significant reduction in content of magnesium resulted from brine and water pretreatment involved in processing smoked and pickled oysters. Perception frequencies for selected sensory characteristics and overall sensory evaluations indicated use of magnesium chloride as an aid to shucking oysters would provide fresh meat with barely acceptable taste characteristics but would provide fresh brine-washed meat, smoked and pickled products with readily acceptable sensory properties.

Key words: oyster Crassostrea gigas, chemical aid to shucking, oyster gaping with magnesium chloride, elemental composition of oyster, oyster products, sensory evaluation of oyster.

RÉSUMÉ

Whyte, J.N.C. et B.L. Carswell. 1983. Moyen chimique pour ouvrir l'huître du Pacifique, Crassostrea gigas. Can. Tech. Rep. Fish. Aquat. Sci. 1238: v + 33 p.

Parmi les produits chimiques examinés, seuls les sels de magnésium ont été à même de provoquer l'écartement des écailles d'huîtres pour en faciliter l'ouverture. L'incidence d'ouverture optimale dans une solution aqueuse de 0.327M de chlorure de magnésium n'était pas affectée par la température mais était dépendante des conditions d'entreposage à sec des huîtres avant l'immersion. L'incorporation de magnésium provenant d'une solution aqueuse de chlorure de magnésium se stabilisait à environ 0.3% du poids humide de la chair d'huître après 12 heures de contact, et était cependant complètement réversible in vivo endéans 24 heures de ré-immersion dans l'eau de mer. Le sodium, le potassium et le calcium étaient les éléments principaux déplacés de l'huître par le traitement au chlorure de magnésium. On considère que l'infusion du magnésium avec déplacement du calcium était responsable pour l'inhibition de la contraction musculaire et par conséquent de l'ouverture de l'huître. Dans l'opération d'ouverture d'huîtres conduite à échelle commerciale le traîtement au chlorure de magnésium fut efficace à plus de 80% et apporta des gains appréciables dans la productivité dûs à une plus grande facilité de vider les huîtres, particulièrement dans le cas d'huîtres en grappes. Le niveau de magnésium diminuait dans la chair d'huître vidée et emballée commercialement. Le traîtement à la saumure était plus efficace que le lavage à l'eau douce pour enlever le magnésium infusé et retenir les hydrates de carbone présents dans la chair d'huître. Pour les huître servant à être fumées ou marinées, on obtenait une réduction considérable du contenu de magnésium en leur faisant subir les traitements à la saumure et à l'eau. La fréquence de perception des charactères sensoriels choisis et l'évaluation sensorielle globale démontrent que l'usage du chlorure de magnésium pour faciliter l'ouverture des huîtres donnerait un produit frais au gôut à peine acceptable mais de la chair lavéc à la saumure ainsi que des produits fumés et marinés à propriétés sensorielles facilement acceptables.

Mots clefs: l'huître, Crassostrea gigas, moyen chimique pour ouvrir l'huître, l'écartement des écailles avec du chlorure de magnésium, composition élémentaire de l'huître, produits préparés à partir d'huître, évaluation sensorielle d'huître.

INTRODUCTION

One of the costly constraints to producing fresh oyster meat is the removal of meat from the shells. Opening oyster shells is difficult, tedious and potentially hazardous from shell lacerations. Rate of shucking depends on ability of the shucker to insert a knife between the shells held closed by a tension in the adductor muscle of up to 36 kg. This painstaking job, normally paid according to output of meat, is attracting fewer recruits each year with a consequent increase in labour costs. In addition hand-shucking of less mature oysters, the native oyster Ostrea lurida or mussels is less economically viable as a result of meat produced per unit effort in removal.

To overcome the disadvantages of hand-shucking an automated shucking machine or techniques for simplifying hand-shucking are required. Development of automated machines is hindered by the irregular shapes, clustering and deeply scalloped shells of the Pacific oyster. Research into opening the bivalve to aid shucking has employed cryogenic freezing, ultrasonic energy, explosive decompression, electrical shock, local dry heating, mechanical shock and vibration, carbon dioxide, microwave heating, vacuum, vacuum with ultrasonic pretreatment, anesthetic agents, enzymes and chemical treatment (Smith, 1971). All but the last treatment exhibited inconclusive results or had no effect on opening the bivalve whereas some chemicals promoted gaping. Steam shucking allows easier removal of meat, fewer accidents and lower labour costs although the steaming equipment adds to capital investment (Brown, 1982). Steaming has the disadvantage of cooking the meat rendering it unsalable as raw fresh product which most purchasers tend to favour.

In the course of our studies on depuration of oysters the ability of magnesium salts to relax the adductor muscle had been noted and potential use of this phenomenon realized. In reviewing this topic a 17 year patent was revealed using chemicals as gaping agents (Welcker and Welcker, 1961). Many of the claims contained in this patent could not be duplicated in our studies and the patent information contained no data on uptake of chemical elements by the treated oysters. Accordingly, this report presents detailed information on effectiveness of different chemicals on relaxing the oyster adductor muscle, the uptake and release of the most effective element - magnesium - under different environmental, laboratory and commercial conditions and the degree to which this cation is retained by the oyster meat subjected to

brining, smoking and pickling processes.

MATERIAL AND METHODS

General. All laboratory tested oysters were tray-cultured specimens purchased from Sunshine Coast Oyster Co., and acclimated to the irrigant seawater in holding facilities at the West Vancouver Laboratory. All test chemicals except magnesium chloride were analytical reagent grade or purest available. Magnesium chloride was purchased as the hexahydrate food grade quality meeting the specifications prescribed under the Food Chemicals Codex of the U.S.A., Appendix 1. Inorganic analyses were performed impartially by an external qualified analyst using a digestion procedure of mixed nitric and perchloric acid to obtain resultant solutions of metals analyzed by a Jarrell Ash 975 Atom Comp Inductively Coupled Argon Plasma Spectrograph. All specimens for analysis were thoroughly homogenized using a Brinkman Polytron.

Influence of chemicals on gaping of oysters.

a) Effect of assorted chemicals on the oyster. Saturated solutions of acetylene, carbon monoxide, carbon dioxide and nitrous oxide gases in seawater at 30°/oo salinity were prepared at 20°C. Oysters (30) were immersed in these resultant solutions for 24h and effects on adductor muscle observed. Solutions of ammonium ferric citrate (0.2g/L), calcium chloride dihydrate (5g/L), potassium iodide (1g/L), potassium chloride (1g/L), lithium carbonate (0.1g/L), sodium metabisulphite (0.1g/L) and sodium lauryl sulphate (0.1g/L) in 30°/oo seawater (shown from preliminary results to be tolerable concentrations) were each added to glass beakers (4L) containing 30 oysters and observations recorded over a 72h immersion period. Similarly 30 oysters were exposed to solutions of magnesium chloride hexahydrate (66.4g/L) and magnesium sulphate heptahydrate (123.2g/L), both tolerable concentrations prepared from distilled water (in seawater the ionic concentration was excessive) and effects recorded over a 24h immersion period, Table 1.

b) Concentration effects of magnesium chloride on incidence of gaping. Oysters (50) were added to 8L of aerated aqueous solutions of magnesium chloride hexahydrate (33.2g/L, 47.4g/L, 66.4g/L and 76.65g/L) at 20°C and the rate of gaping recorded at selected intervals up to a total immersion of 24h,

Fig. 1.

c) Effect of temperature on gaping rate in magnesium chloride. Oysters (50) were acclimated at 5, 10 and 20°C for 24h prior to immersion in 8L aqueous solutions of magnesium chloride hexahydrate (66.4g/L or 0.327M) maintained at these temperatures. At selected intervals up to 24h the number of gaping oysters was recorded to provide rate of gaping, Table 2.

d) Effect of preconditioning on rate of gaping. Oysters (50) were stored out of water for 24h at 20°C prior to immersion in 8L aqueous magnesium chloride (0.327M) at 20°C. Oysters (50) taken directly from 10°C seawater were immersed in magnesium chloride (0.327M) at 20°C. At intervals up to 24h the incidence of gaped animals was recorded, Table 3.

e) Uptake and release of magnesium by the oyster. Oysters (302) were dry stored at 20°C for 24h prior to immersion in aqueous magnesium chloride (50L, 0.327M) maintained at 20°C in 4 aerated tanks. At specific intervals the number of gaping versus closed oysters were counted and 10 gaped animals were sampled for magnesium content. At 12h intervals 10 gaping oysters were transferred from the magnesium chloride bath to a flushing seawater tank for recovery and after 24h these animals were sampled for magnesium content. Only animals gaping within the first hour were used for the magnesium uptake study. Specimens removed from the magnesium chloride bath for analysis were washed with cold fresh water, drained for 5 minutes ensuring no water from the shell entered the shell cavity, the adductor muscle was severed and the body meat without further fresh water washing was collected in zip-lock plastic bags on ice. Samples as obtained were frozen until the termination of the experiment. All samples were then partially thawed, homogenized with a Brinkman Polytron prior to elemental analysis, Table 4 and Figure 2.

f) Distribution of magnesium in oyster flesh. Oysters (12) untreated with magnesium were shucked and the adductor muscle (18.63g) carefully separated from the remaining body flesh (250.52g). Oysters (12) subjected to exposure of magnesium chloride (0.327M) for 16h at 20°C were separated into adductor muscle (20.16g) and remaining body flesh (281.84g). Tissue samples without further water washing were then homogenized prior to analysis for magnesium, Table 5.

Effectiveness of magnesium chloride under commercial conditions.

a) Incidence of gaping in commercial operations. At a commercial shucking

plant a fibreglass tank (750L) fitted with a recirculation pump was filled with potable fresh water (700L), magnesium chloride hexahydrate (46.48kg) added and the contents mixed thoroughly for 0.5h. Bottom oysters, from Nanoose Bay Oyster Co., (56) unwashed and dry stored for 16h were stacked 1 deep in shallow perforated plastic stacking trays (60cm x 40cm x 12cm, 18L, Allibert, #11-020), and unwashed bottom oysters (154) were stacked 4 deep in larger plastic stacking containers (60cm x 40cm x 24cm, 37L, Allibert, #11-037). String cultivated oysters, from Esperanza Sea Farms Ltd., (55) washed with fresh water, were declustered, and stacked in 18L plastic trays and unwashed clustered string oysters (195) were stacked in 37L containers. String oysters (41) were subjected to impact and the animals with fractured shells stacked in a 37L stacking container. All trays and containers were positioned in the aqueous magnesium chloride bath (0.327M, 15°C, pH 7.5) for 16h except the container with the damaged oysters which was immersed for only 2h. Magnesium-treated oysters were counted for incidence of gaping. Gaped bottom oysters (100) were reimmersed in seawater for a period of 2h and incidence of gaping recorded, Table 6.

b) Content of magnesium in oysters shucked and packaged in a commercial manner. Treated oysters were shucked by hand, washed with potable fresh water for less than 3 minutes and packaged in 227g (8 oz.) plastic tubs. Untreated bottom and string oysters were shucked, washed and packaged in an identical manner for comparative purposes. These commercially prepared samples were returned to the laboratory on ice. Oysters were homogenized with the liquor in the container while others were rinsed in cold fresh water for 5 sec, blotted, then homogenized prior to analysis, Tables 7 and 8.

Residues of magnesium in processed oysters and sensory evaluation of products.

a) Fresh water and brine leaching of magnesium-treated oysters. Oysters [24, averaging 9.6 (SD 1.04) cm in length, 6.30 (SD 0.59) cm in width and 3.80 (SD 0.51) cm in thickness] gaped by immersion in magnesium chloride (0.327M) for 16h at 20°C were shucked and weighed (497.4g). Distilled water (994.8g) was added and contents of the beaker (4L) stirred by a magnetic stirring bar. Oysters (6) were removed randomly by tweezers, drained for 20 sec and weighed collectively after 30 min (121.09g), 60 min (111.43g), 120 min (125.22g) and 240 min (103.88g) immersion. Leached specimens were

homogenized for magnesium analysis and the leachate (1007.3g) in the beaker was centrifuged then filtered through fibreglass filters and a portion (100mL) analyzed for carbohydrate content by the phenol-sulphuric acid procedure (Dubois et al., 1956).

Similarly from the same batch of magnesium treated oysters specimens [24, averaging 9.65 (SD 0.81) cm in length, 6.00 (SD 0.70) cm in width and 3.70 (SD 0.51) cm in thickness] were shucked (491.06g) and added to brine (3% aqueous sodium chloride, 982.1g) and stirred. Oysters (6) were removed, drained and weighed after 30 min (115.60g), 60 min (96.70g), 120 min (79.04g) and 240 min (92.20g) immersion. Leachate (1068.5g) was prepared for carbohydrate analysis, as described previously, and oysters homogenized for elemental analysis. Control specimens (6) from the same batch of magnesium-treated oysters were shucked, not washed with water, and homogenized for analysis, Table 9.

b) Preparation of smoked oysters for chemical and sensory analyses. Oysters (720), harvested at the same time and location, were irrigated for 3 weeks at the West Vancouver Laboratory to eliminate harvest and transportation shock. Fresh oyster control samples were taken for sensory evaluation (60) and chemical analysis (12). Oysters (300) for gaping were placed as single layers in stacked trays in a fibreglass tank containing aqueous magnesium chloride (0.327M, 700L, 20°C) for 16h (97% gaped). Treated oysters (240) were shucked, sampled for analyses, then soaked in brine (3%) for 2h at 20°C. After rinsing in fresh water samples were taken for analyses, then heated in boiling water for 3 min to firm the meat and cooled rapidly in cold water. Further firming of meat was produced by steaming single layers of oysters in a steam cooker (100°C) for 20 min to afford pre-smoked oysters, which were sampled for analyses. After cooling the oysters were smoked in an Afos Mini Kiln for 40 min at 50°C and samples taken for analyses. Untreated oysters (170) were shucked, brined (3%) for 2h, rinsed with fresh cold water and sampled for sensory analysis. Leached oysters were firmed by boiling in water and steamed prior to being smoked and sampled for chemical, Table 10, and sensory evaluation as control smoked oysters.

c) Preparation of pickled oysters for chemical and sensory analyses. Oysters (150) gaped by treatment with magnesium chloride, as per the smoked product, were shucked, sampled for analyses, then a portion (1800mL) heated slowly at 100°C in 3% sodium chloride (1800mL) until the mantle curled

(3 min). Oysters were drained and cooled prior to packing in Mason jars with bay leaves and thin slices of lemon. A pickling sauce was prepared by heating gently for 0.5h vinegar (950mL), water (1000mL), cloves (15g), whole allspice (15g), whole black peppers (15g) and 1 blade of mace. The cooled sauce was poured into the Mason jars to the top and jars sealed and stored in a refrigerator for 14 days. Shucked untreated oysters (1400mL) were processed as above to provide control pickled oysters. Samples of the pickled oysters were subjected to chemical, Table 11, and sensory analysis.

d) Sensory evaluation. Flavour and odour of oysters were assessed by a taste panel consisting of 10 panelists. Samples of fresh and brined Oysters were sealed in plastic pouches and steamed for 5 min at 100°C, before being presented to each panelist whereas the smoked and pickled products were unheated. All samples were left whole for evaluation and presented in triplicate and random order to the panel. Initially the panelists were requested to complete form Appendix 2 assessing individual aroma, taste and texture characteristics, which provided perception frequencies for individual sensory terms, Tables 12 and 13. Using these criteria panelists were requested to complete the overall acceptability, aroma, taste and texture terms scored from 1-9 corresponding to dislike-like extremely, Appendix 3. Mean values including standard deviations were calculated, Table 14, and for statistical comparison scores were subjected to the Student's-t-test, Table 15.

RESULTS AND DISCUSSION

When oysters were subjected for 24 hours to saturated seawater solutions of acetylene, carbon dioxide, nitrous oxide and carbon monoxide only the latter gas inhibited adductor muscle contraction probably as a result of toxicity, Table 1. Salts of the trivalent ferric ion, the monovalent sodium, lithium and potassium ions and the divalent calcium ion as solutions in seawater provided no narcotic effects on the adductor muscle but the detergent action of sodium lauryl sulphate even at low concentrations caused severe tissue disintegration. Only solutions of the divalent magnesium ion either as the chloride or sulphate salts in freshwater resulted in strong narcotic influences on the adductor muscles which were unable to contract and

close the bivalves, Table 1. Although the sulphate of magnesium proved effective in gaping oysters all subsequent work was conducted on aqueous solutions of the chloride salt which resembled more closely the anionic composition of seawater containing 55.04% chloride compared to 7.68% sulphate (Sverdrup et al., 1942). Magnesium chloride as the food-grade hexahydrate, with specifications contained in Appendix 1, proved the most convenient form of the salt to use. Dissolution in potable fresh water eliminated any potential seawater contaminants. The influence of magnesium chloride concentrations on incidence of gaping with time of exposure was considered optimal at 66.4g/L of hexahydrate, compared to weaker solutions, 47.4g/L and 33.2g/L which proved less effective and the apparent lack of any advantages from 76.65g/L, Figure 1. A solution of 66.4g/L of the hexahydrate, or 0.327M aqueous magnesium chloride, at 31.1°/oo salinity was equivalent to good oceanic seawater but contained 6.90 times the 1.1497g/L of magnesium normally associated with 31.1°/oo oceanic seawater. Although no significant differences in rate of gaping were apparent when oysters were treated with 0.327M magnesium chloride at 5, 10 and 20°C, Table 2, preconditioning of the animals prior to immersion was critical. Dry storage of oysters for 24 hours before treatment with magnesium chloride increased the rate of gaping relative to that of animals taken from seawater and exposed immediately to the chemical, Table 3. This increased incidence of gaping was considered to reflect the necessity of the dry-stored animals to remove accumulated metabolic by-products by pumping soon after immersion in water with the consequent effect of infused magnesium into the adductor tissue.

Uptake of magnesium by oysters attained a plateau after 12 hours of immersion in 0.327M magnesium chloride and corresponded to an equilibrium inclusion of about 0.30% of the wet weight, Figure 2. That this inclusion of magnesium was reversible in vivo to various degrees was demonstrated by transferral of specimens treated for 12, 24, 36 and 48 hours into running seawater and the consequent recovery of normal magnesium levels in these oysters within 24 hours, Figure 2. Most of the animals which had been transferred to seawater recovered "physiologically" after 24 hours as measured by the animals ability to close rapidly if disturbed and that on morphological examination no apparent damage had occurred. Exceptions to this were found in animals subjected to 48 hour exposure to magnesium chloride. About 30% of these oysters transferred to seawater for 24 hours

continued to gape and although still responding to tactile stimuli, retraction of the adductor muscle occurred slowly. In addition these gaping animals in the recovery tank after 24 hours showed noticeable retraction of the mantle from the shell periphery, conditions not evident in animals immersed for up to 36 hours in the magnesium chloride solution. These data indicated that exposure for 12 hours to 0.327M magnesium chloride would effect gaping of oysters and as an aid to shucking would provide oyster meat suitable for the fresh market category.

Comparison of the total elemental composition of fresh oysters with oysters immersed in 0.327M magnesium chloride solution for 48 hours at 20°C, clearly illustrated the displacement of sodium, calcium and potassium by 87, 91 and 28% respectively as major cations in oyster tissue and a 560% increase in the magnesium level, Table 4. Phosphate, at a level comparable to that of sodium, resisted displacement from the tissue exposed to aqueous magnesium chloride presumably through association with organic molecules. Strontium and boron were the only other elements significantly leached from the tissue, Table 4. In fresh oysters the distribution of magnesium in adductor muscle, constituting 6.9% of the wet meat, relative to the remaining body tissue on a dry-weight basis, was 1:1.99. Change in this ratio to 1:1.87 on exposure of the oyster to 0.327M magnesium chloride demonstrated the assimilation of magnesium at the same rate into the different tissue types of the mollusc, Table 5.

The infusion of magnesium with displacement of calcium ions was considered responsible for adductor muscle relaxation by interrupting the basic process of muscle contraction involving the thick and thin myofilaments as represented schematically in Figure 3. Replacement of calcium ions would inhibit unblocking of myosin-binding sites on the actin filaments in the adductor muscle and increased magnesium levels would enhance dissociation of the actin-myosin bridged complex by increased myosin-ATPase activity. These processes would inhibit the necessary cross-bridging between myosin and actin fibrils essential for muscle contraction resulting in this case in adductor muscle relaxation and gaping of the oyster. This mechanism also accounted for the gaping of mussels and clams which proved over 80% effective within 1 hour of treatment with 0.327M magnesium chloride.

Flesh of all animals tested to this stage was not washed after shucking to provide information on the <u>maximum</u> inclusion levels of magnesium under the

conditions specified. Normal commercial practice involves washing the shucked meat which would reduce the magnesium content. Residual magnesium associated with commercially processed oysters was therefore investigated.

At a commercial oyster shucking plant dry stored bottom oysters were stacked 1 deep in 18L shallow plastic perforated trays and 4 deep in 37L stacking trays. String cultivated oysters washed with fresh water were declustered and stacked in shallow trays or unwashed and placed in deep perforated trays. To simulate damage occurring in washer-tumblers, used to break clusters, the shells of string oysters were broken and the animals stacked in 37L trays. All these trays were positioned in a 700L fibreglass tank containing 0.327M magnesium chloride solution at 15°C for 16 hours except the last container with the broken shells which was immersed for only 2 hours. In a production system, filtration and antibacterial U.V. lights would be included in a recirculating mode of operation. Incidence of gaping within the 16 hour immersion period was in excess of 80% of the oysters except for bottom cultured animals stacked 4 deep on top of each other, Table 6. This result indicated the need for reasonable separation of single oysters within the treatment tank, a requirement not necessary for cluster oysters already spacially separated. Rapid gaping of 58.5% oysters with damaged shells clearly illustrated the rate of assimilation of the magnesium cation into the adductor muscle with subsequent relaxation. Relaxation rate was a function of the incidence of pumping of these molluscs with tightly closed animals impervious to any effects of the magnesium in the medium. Resultant differences in percentage gaping, Tables 3 and 6, also reflected natural biological variance in dry-stored oysters. Only 3% of the gaped oysters reimmersed in seawater for 2 hours had leached enough magnesium to allow contraction of adductor muscles, Table 6.

The treated bottom and string oysters were shucked, washed with potable fresh water for less than 3 minutes and packaged in 227g (8 oz.) plastic tubs. Untreated bottom and string oysters were shucked, washed and packaged in an identical commercial manner for comparative purposes. As bleeding of the oysters would affect residual magnesium, analyses were conducted on oysters homogenized with the liquor in the containers and on oysters rinsed in cold water to remove associated liquor, blotted, then homogenized for analyses. This washing simulated oysters water-rinsed prior to breading and deep frying.

Lower levels of magnesium 0.16 and 0.20% in the commercially washed shucked meat, from treated bottom and string oysters respectively, Tables 7 and 8, contrasted with the 0.30 to 0.35% associated with unwashed shucked meat from treated oysters described previously. Additional lowering of magnesium levels by 13.1 and 6.4% resulted from water-rinsing of packaged meat from untreated bottom and string oysters respectively and similarly reductions of 13.9 and 18.5% in magnesium content of water-rinsed packaged bottom and string oysters previously treated with magnesium chloride, Tables 7 and 8 respectively. These data on commercially washed shucked meat and the loss in "bleeding" while in the packages suggested that further processing with water of the fresh meat into products or the preparation of products contained in aqueous medium, eg. pickled products, would result in still further reduction of magnesium residues.

Effects of leaching, with distilled water and brine solution, on shucked oysters previously treated with magnesium chloride were investigated, Table 9. Unwashed meat after shucking provided a control level of 0.34% magnesium in wet tissue, similar to previous values for this treatment. Although an increased rate of leaching was suggested for distilled water based on wet weight values, a 6.5% increase and 2.3% decrease in moisture content of the meat leached with fresh and brined water respectively when taken into account resulted in a similar displacement of magnesium in both solutions up to 1 hour after immersion but thereafter the brine solution proved more effective, Table 9. Brine treatment for 4 hours caused a 71.1% decrease in content of magnesium to a level comparable with the 3788 ppm dry weight of magnesium present in the untreated oysters. Carbohydrate analysis of the leachate indicated a loss of 1.11% and 0.32% of the weight of the wet oyster as total carbohydrate into the fresh- and brined-water respectively. Relative to fresh water, brine was more effective in displacing magnesium from tissue and retained a higher proportion of total carbohydrate normally accounting for 5.7% of wet meat in oysters (Whyte and Englar, 1982). Importantly, these shucked oysters were still alive after 4 hours of leaching, as demonstrated by visible rhythmic contraction of the heart, suggesting the term "fresh" would still apply to these oysters. Fresh brine-washed oysters shucked with the aid of magnesium chloride, but with magnesium levels comparable to untreated oysters, was therefore feasible.

Brine treatment forms an integral part of smoking and pickling oysters

consequently the decrease in residual magnesium with these processes was investigated. Smoked oysters were prepared from treated and untreated oysters by the following process. Shucked oysters were mixed with 3% sodium chloride for 2 hours, rinsed carefully with fresh water, heated in boiling water for 3 minutes to firm the meat, cooled in water, then steamed in single layers for 20 minutes at 100°C and finally smoked for 40 minutes at 50°C. Chemical analysis of oyster meat at selected stages of the process, Table 10, indicated a considerable reduction in most inorganic elements from the washing and steaming treatments prior to smoking. Magnesium in the brined product from treated oysters was similar to the background level in the untreated mollusc and was reduced below this level by subsequent washing prior to smoking, Table 10.

Pickled oysters were processed by cooking the shucked treated and untreated oysters for 3 minutes in boiling brine solution and steeping the resultant meat in a pickling sauce for 14 days. Magnesium in treated oysters was reduced 75% by the process of pickling which provided a product containing less of this element than untreated oysters, Table 11. Except for magnesium, sodium and phosphate the levels of inorganic elements were similar in pickled meats from magnesium treated and untreated oysters. Samples analyzed for inorganic elements were subjected to sensory evaluation by a taste panel.

Individual characteristics of aroma, taste and texture were evaluated, Appendix 2, to provide perception frequencies for each descriptive term. A comparison of the most appropriate descriptive terms for fresh and brined meats from magnesium treated and untreated oysters, Table 12, illustrated the detection of a bitter and metallic taste to the flesh of fresh oysters with magnesium inclusion level of 0.40% wet weight. Reduction of this level to 0.13% by brining negated these adverse taste characteristics but appeared to toughen the tissue, Table 12. Perception frequencies for selected sensory characteristics of pickled and smoked oysters clearly illustrated that no adverse organoleptic properties were encountered from use of oysters shucked with the aid of magnesium, indeed, an enhanced degree of sweetness was apparent in smoked oysters prepared from treated molluscs, Table 13.

Based on perception of individual characteristics a hedonic rating of acceptability, aroma, taste and texture was scored from 1, for dislike extremely, to 9, for like extremely, Appendix 3. Resultant numerical

evaluation of fresh, brined, pickled and smoked oysters, Table 14, demonstrated the lowest mean value, 4.8, was obtained for the taste of fresh meat from oysters treated with magnesium, a value equivalent to "neither like nor dislike" on the hedonic scale. Interestingly scores were consistently higher in all categories for pickled oysters from magnesium treated stock, Table 14.

Scores for sensory evaluation when subjected to a Student's-t-test demonstrated that, although the overall acceptability for all products passed the test, significant differences were apparent in the taste of fresh meat and the texture of brined meat from oysters shucked with and without the aid of magnesium, Table 15. These organoleptic data suggested that use of magnesium as an aid in shucking oysters would provide fresh meat with marginal taste acceptance, but would provide fresh brine-washed meat and processed products with acceptable sensory properties.

Significant productivity gains from increased ease of shucking, particularly clustered, oysters and the demonstrated sensory acceptability of these oysters when brine washed or processed would suggest potential use for magnesium chloride in the industry as a processing aid. As residual magnesium remains in the final product it must be regarded as a food additive for regulatory purposes. This would require a submission to the Health Protection Branch in accordance with Div. 16, Section B.16.002, of the Food and Drug Regulations requesting amendment to Div. 16, Table IV, item M.1, columns I and II of these regulations. Salts of magnesium are extensively used in the food industry as additives, with a recent amendment to food additive regulations allowing inclusion of 0.3% magnesium chloride in tofu (Anon, 1982). A similar amendment would be required for use of this magnesium salt as an aid to shucking molluscs.

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Table 1. Effect of various chemicals on the oyster, Crassostrea gigas.

Chemical	Max. tolerable conc. examined	Exposure time (h) (% survival)	Narcotic effect on adductor muscle	Observations
Acetylene	saturated, 20°C	24 (100)	none	Valves tightly closed.
Carbon monoxide	saturated, 20°C	24 (100)	moderate	Slows contraction of adductor muscle.
Carbon dioxide	saturated, 20°C	24 (100)	none	Normal valve activity.
Nitrous oxide	saturated, 20°C	24 (100)	none	Normal valve activity.
Potassium chloride	1g/L	72 (100)	none	Normal valve activity for 48h; then shut tightly.
Potassium iodide	1g/L	72 (100)	none	Normal valve activity for 48h; then shut tightly.
Calcium chloride (dihydrate)	5g/L	72 (100)	none	Normal valve activity.
Lithium carbonate	0.1g/L	72 (100)	none	Normal valve activity for 48 hr; then shut tightly.
Sodium metabisulphite	0.1g/L	72 (100)	none	Normal valve activity.
Magnesium chloride (hexahydrate)	66.4g/L	24 (100)	strong	Oysters unable to contract after prolonged exposure.
Magnesium sulphate (heptahydrate)	123.2g/L	24 (100)	strong	As above.
Ammonium ferric citrate	0.2g/L	72 (100)	none	Normal valve activity.
Sodium lauryl sulphate	0.1g/L	72 (0)	none	Tissue disintegration very evident. Detergent very insol. in seawater.

Table 2. Incidence of gaping on treating oysters with 0.327 M magnesium chloride solution at 5, 10 and 20°C.

Time exposed (h)	% Gaping at 5°C	% Gaping at 10°C	% Gaping at 20°C
1	58	32	44
2	66	62	68
4	76	72	68
6	78	72	70
12	88	88	90
24	92	96	94

Table 3. Comparison of incidence of gaping of oysters dry stored at 20°C for 24 hours, with fresh oysters taken directly from 10°C seawater, and subsequently exposed to 0.327 M magnesium chloride solution at 20°C.

Time exposed (h)	Dry stored % gaping	Fresh % gaping
1	44	6
2	68	12
4	68	20
6	70	24
12	90	48
24	94	80

Table 4. Comparison of elemental composition of fresh oysters with oysters immersed in magnesium chloride solution for 48h

Element	Fresh Oysters		Treated Oysters	
	Dry wt. ppm flesh	Wet wt. ppm flesh	Dry wt. ppm flesh	Wet wt. ppm flesh
Sodium	23800	4165	3120	546
Phosphate	21300	3728	21900	3832
Potassium	7490	1311	5400	945
Calcium	6250	1094	582	102
Magnesium	3300	578	18500	3238
Zinc	1410	247	970	170
Iron	231	40	220	39
Aluminum	119	21	114	20
Copper	112	20	72.9	13
Strontium	30.5	5	6.2	1
Boron	17.8	3	3.49	0.6
Cadmium	12.6	2	14.7	3
Manganese	12.3	2	9.97	2
Titanium	6.3	1	5.3	1
Barium	1.02	0.2	1.05	0.2
Vanadium	0.94	0.2	0.73	0.1
Below detection limit				
Antimony	< 8	-	< 8	-
Arsenic	< 15	-	< 15	-
Beryllium	< 0.015	-	< 0.015	-
Bismuth	< 25	-	< 25	-
Chromium	< 1.5	-	< 1.5	-
Cobalt	< 1.0	-	< 1.0	-
Lead	< 4	-	< 4	-
Molybdenum	< 2	-	< 2	-
Nickel	< 1.5	-	< 1.5	-
Silver	< 5	-	< 5	-
Tin	< 1.5	-	< 1.5	-

Table 5.

Magnesium content of adductor muscle and remaining meat, of fresh oyster and oyster immersed in magnesium chloride (0.327 M) for 16 hours at 20°C.

	Moisture Content %	Magnesium Content: Dry weight flesh ppm	Magnesium Content: Wet weight flesh ppm
Fresh oyster, adductor muscle	77.5	2,000	450
Fresh oyster, remaining meat	83.6	3,970	651
Treated oyster, adductor muscle	76.3	9,610	2278
Treated oyster, remaining meat	80.2	18,000	3564

Table 6. Incidence of gaping on treating oysters with magnesium chloride solution, at a commercial oyster shucking plant.

Oyster Type and Conditions	Immersion Time (h)	Gaping %
Bottom oysters, unwashed, stacked 1 deep in 18L (shallow) perforated plastic containers.	16	84.0
Bottom oysters, unwashed, stacked 4 deep in 37L (deep) perforated plastic containers.	16	51.3
String oysters, prewashed with fresh water, declustered, stacked in 18L perforated plastic containers.	16	87.0
String oysters, unwashed, clustered, stacked in 37L perforated plastic containers.	16	81.5
String oysters, bills broken to simulate damage caused in washer-tumbler to break clusters.	2	58.5
Bottom gaped oyster reimmersed in seawater for 2 hours.	-	97

Table 7. Content of magnesium in bottom oysters, shucked and packaged in a commercial manner.

Description and Treatment of Oysters from 227g Containers	Magnesium Content Dry weight ppm	Wet weight ppm
No magnesium chloride treatment, homogenized with liquor of container.	2050	390
No magnesium chloride treatment, rinsed in cold water, blotted, homogenized.	1740	339
Treated 16h in magnesium chloride, homogenized with liquor of container.	8090	1634
Treated 16h in magnesium chloride, rinsed in cold water, blotted, homogenized.	6830	1407

Table 8. Content of magnesium in string oysters, shucked and packaged in a commercial manner.

Description and Treatment of Oysters from 227g Containers	Magnesium Content Dry weight ppm	Wet weight ppm
No magnesium chloride treatment, homogenized with liquor of container.	2900	502
No magnesium chloride treatment, rinsed in cold water, blotted, homogenized.	2280	470
Treated 16h in magnesium chloride, homogenized with liquor of container.	10,100	1999
Treated 16h in magnesium chloride, rinsed in cold water, blotted, homogenized.	7580	1630

Table 9. Fresh water and brine solution leaching of shucked oysters previously treated with magnesium chloride (0.327 M) for 16 hr at 20°C.

Leaching time	Distilled water leach			Sodium chloride 3% solution leach		
	Moisture %	Magnesium ppm		Moisture %	Magnesium ppm	
		Wet weight	Dry weight		Wet weight	Dry weight
0	79.7	3390	16700	79.7	3390	16700
30 min	84.9	1489	9860	79.1	2025	9690
60 min	84.9	1271	8420	79.0	1684	8020
120 min	85.2	1206	8150	78.4	1568	7260
240 min	86.2	1050	7610	77.4	1069	4730

Table 10. Changes in elemental composition resulting from the process of smoking untreated and magnesium treated oysters.

Elements ppm dry wt	Untreated oysters		Treated oysters			
	Fresh shucked	Smoked	Fresh shucked	Brined	Steamed	Smoked
Sodium	37500	5400	3290	8670	1960	2200
Phosphate	18300	16200	18600	21900	16100	14900
Potassium	13200	4570	11000	10900	4380	4160
Magnesium	5740	986	25500	6580	3280	3120
Calcium	3190	1820	2450	1680	830	563
Zinc	1820	1900	1730	2210	1630	1610
Iron	175	201	161	222	166	166
Aluminum	152	117	87	108	103	86
Copper	122	118	103	147	98	100
Strontium	39	9	25	13	6	5
Boron	31	6	26	14	8	8
Cadmium	21	20	18	25	17	19
Manganese	11	8	12	11	8	6

Table 11. Elemental composition of pickled products from untreated and magnesium treated oysters.

Elements ppm dry wt	Pickled untreated oysters	Pickled treated oysters	Fresh shucked treated oysters used in pickling
Sodium	2580	607	2110
Phosphate	15000	20200	20500
Potassium	4760	4190	10500
Magnesium	843	3670	14900
Calcium	1520	1320	2120
Zinc	1330	1180	1560
Iron	177	209	166
Aluminum	105	130	79
Copper	122	120	104
Strontium	10	6	16
Boron	7	9	18
Cadmium	18	21	19
Manganese	7	6	12

Table 12. Perception frequencies for selected sensory characteristics of fresh and brined meats from untreated (-Mg) and magnesium treated (+Mg) oysters.

Treatment (magnesium % wet wt) Characteristics	Strong, %		Weak, %		Not perceived, %	
	-Mg	+Mg	-Mg	+Mg	-Mg	+Mg
Fresh (-Mg = 0.0643 +Mg = 0.4004)						
Typical oyster aroma	48	29	42	52	10	19
Sweet taste	29	10	48	24	23	66
Metallic taste	5	19	42	52	53	29
Bitter taste	0	43	19	33	81	24
Chewy texture	48	33	42	57	10	10
Brined (+Mg = 0.1323)						
Typical oyster aroma	33	25	38	54	29	21
Sweet taste	25	25	42	42	33	33
Metallic taste	8	13	17	33	75	54
Bitter taste	4	13	13	42	83	46
Chewy texture	29	38	42	54	29	8

Table 13. Perception frequencies for selected sensory characteristics of pickled and smoked meats from untreated (-Mg) and magnesium treated (+Mg) oysters.

Treatment (magnesium % wet wt) Characteristics	Strong, % -Mg	Strong, % +Mg	Weak, % -Mg	Weak, % +Mg	Not perceived, % -Mg	Not perceived, % +Mg
Pickled (-Mg = 0.0196 +Mg = 0.0840)						
Typical oyster aroma	8	4	33	25	59	71
Sweet taste	29	25	42	54	29	21
Metallic taste	0	0	17	17	83	83
Bitter taste	13	13	21	17	66	70
Chewy texture	38	38	33	29	29	33
Smoked (-Mg = 0.0367 +Mg = 0.1323)						
Typical oyster aroma	12	9	33	30	55	61
Sweet taste	17	26	42	48	41	26
Metallic taste	4	9	33	22	63	69
Bitter taste	8	4	17	17	75	79
Chewy texture	21	35	42	35	37	30

Table 14. Sensory evaluation of fresh, brined, pickled and smoked meats from untreated (-Mg) and magnesium treated (+Mg) oysters.

Treatment	Acceptability ($\bar{x}$, SD)	Aroma ($\bar{x}$, SD)	Taste ($\bar{x}$, SD)	Texture ($\bar{x}$, SD)
Fresh -Mg	7.0 (1.2)	6.4 (1.4)	7.0 (1.1)	6.7 (1.1)
Fresh +Mg	5.6 (1.6)	5.8 (1.1)	4.8 (1.3)	6.4 (1.6)
Brined -Mg	6.1 (1.6)	5.9 (1.2)	6.2 (1.4)	6.8 (1.1)
Brined +Mg	5.9 (1.3)	5.7 (1.4)	5.6 (1.1)	5.6 (1.0)
Pickled -Mg	7.3 (0.7)	7.0 (1.1)	7.2 (0.6)	7.4 (0.4)
Pickled +Mg	7.7 (0.7)	7.2 (1.2)	7.6 (0.7)	7.5 (0.7)
Smoked -Mg	5.4 (1.6)	5.9 (1.2)	5.4 (1.5)	5.8 (1.0)
Smoked +Mg	5.2 (1.6)	5.5 (1.2)	5.1 (1.5)	5.4 (1.6)

Table 15. Summary of students t test for differences between means on sensory evaluation of fresh, brined, pickled and smoked meats from untreated (-Mg) and magnesium treated (+Mg) oysters.

Treatment	Acceptability	Aroma	Taste	Texture
Fresh -Mg Fresh +Mg	$P(\|t\| \geq 1.83) > 0.05$ Accept Ho *1	$P(\|t\| \geq 0.90) > 0.20$ Accept Ho *1	$P(\|t\| \geq 3.32) < 0.05$ Reject Ho *1	$P(\|t\| \geq 0.41) > 0.50$ Accept Ho *1
Brined -Mg Brined +Mg	$P(\|t\| \geq 0.41) > 0.50$ Accept Ho *2	$P(\|t\| \geq 0.31) > 0.50$ Accept Ho *2	$P(\|t\| \geq 0.94) > 0.20$ Accept Ho *2	$P(\|t\| \geq 2.32) < 0.05$ Reject Ho *2
Pickled -Mg Pickled +Mg	$P(\|t\| \geq 0.88) > 0.20$ Accept Ho *2	$P(\|t\| \geq 0.20) > 0.50$ Accept Ho *2	$P(\|t\| \geq 1.21) > 0.20$ Accept Ho *2	$P(\|t\| \geq 0.31) > 0.50$ Accept Ho *2
Smoked -Mg Smoked +Mg	$P(\|t\| \geq 0.26) > 0.50$ Accept Ho *2	$P(\|t\| \geq 0.72) > 0.20$ Accept Ho *2	$P(\|t\| \geq 0.40) > 0.50$ Accept Ho *2	$P(\|t\| \geq 0.60) > 0.50$ Accept Ho *2

*1 $t_{0.05(2)12} = 2.179$
*2 $t_{0.05(2)14} = 2.145$
N.B. Ho: $X_1 = X_2$

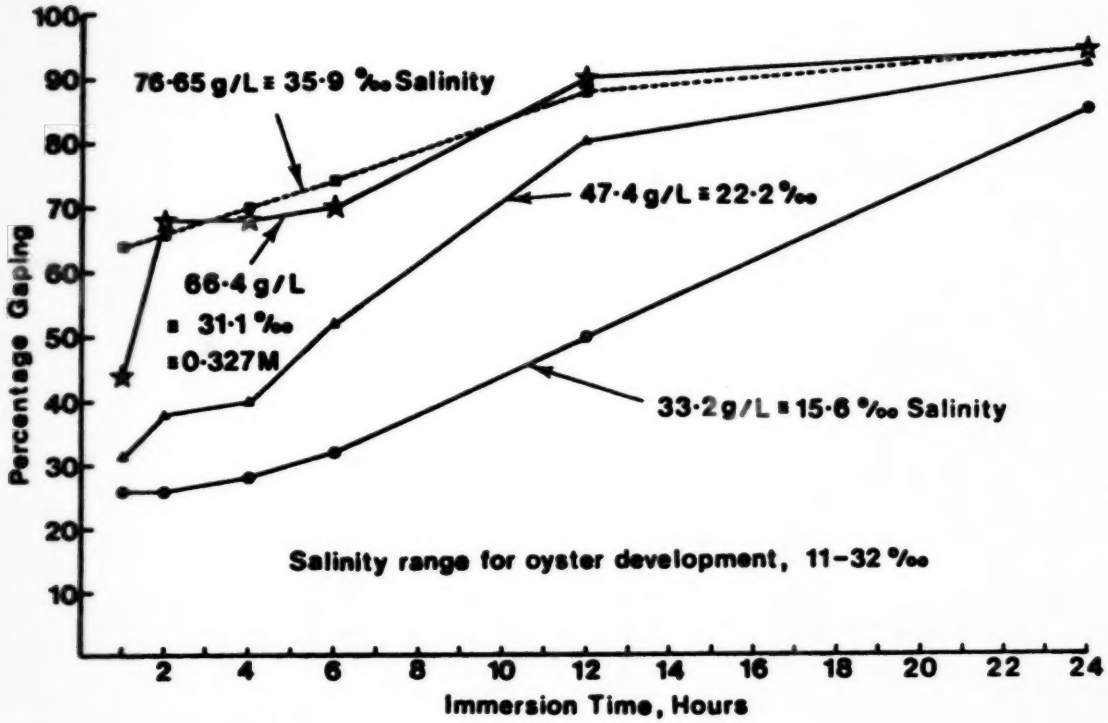

Fig. 1. Influence of concentration of magnesium chloride hexahydrate on gaping of the Pacific oyster.

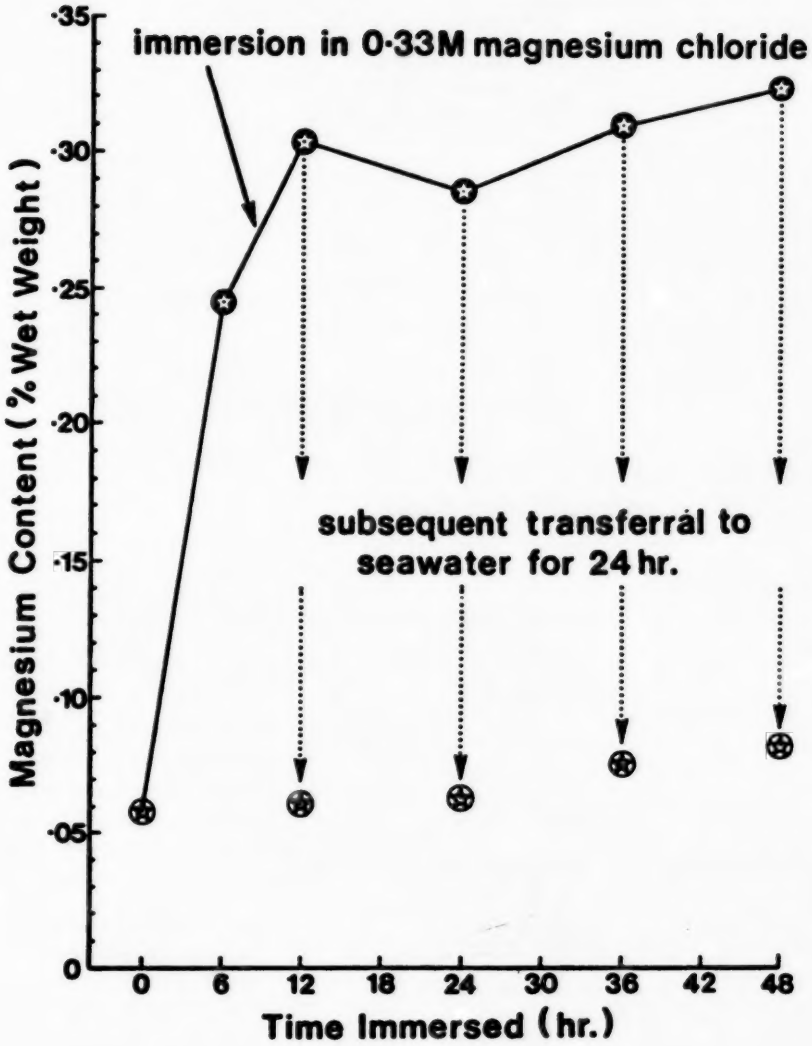

Fig. 2. Absorption and release of magnesium by the Pacific oyster.

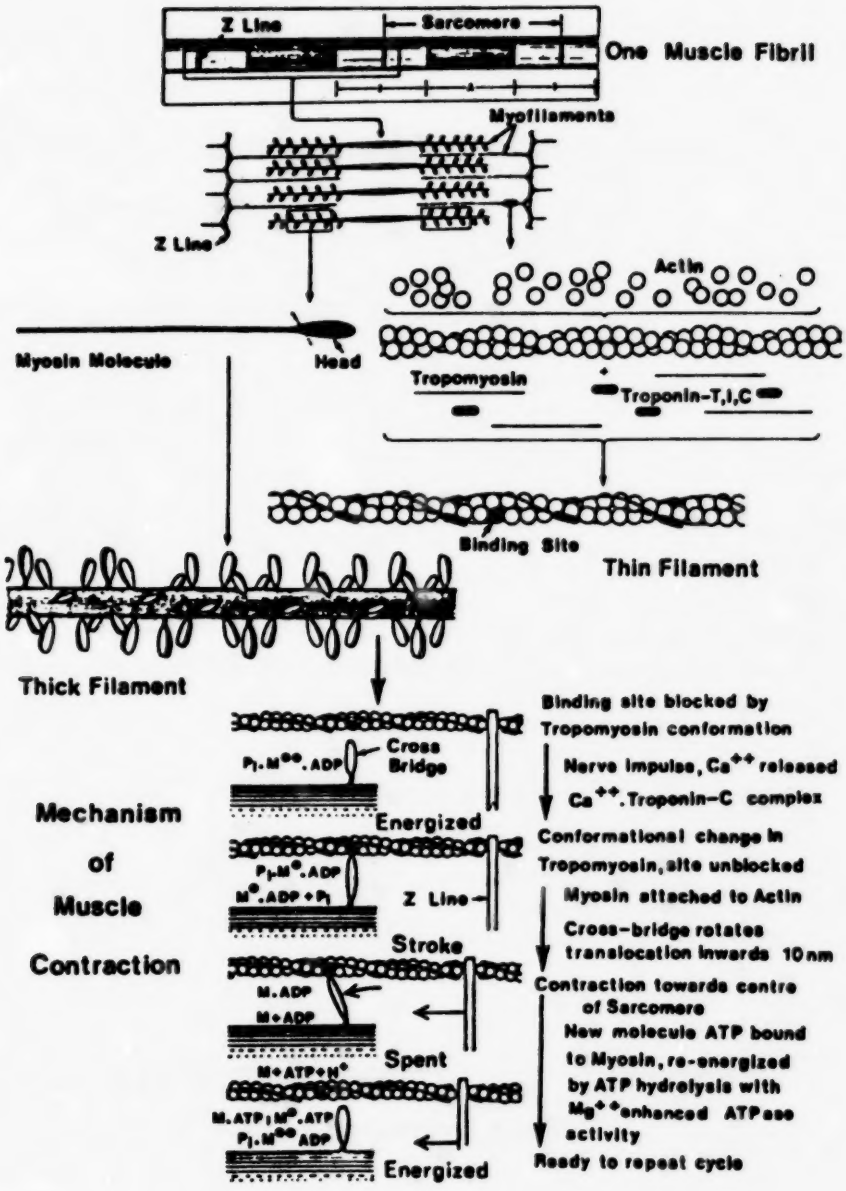

Fig. 3. Schematic diagram of molecular architecture of thick and thin filaments from myosin and actin molecules respectively and their interaction in contraction mechanism of striated muscle.

Appendix 1.

Magnesium Chloride Hexahydrate, $MgCl_2 \cdot 6H_2O$ (Mol. wt. 203.3)

a) Food grade specifications (from Food Chemical Codex, U.S.A., p. 471).

Description. Colourless, odourless, flakes or crystals. It is very deliquescent. It is very soluble in water and freely soluble in alcohol.

Specifications:- Assay; Not less than 99.0 percent and not more than the equivalent of 105.0 percent of $MgCl_2 \cdot 6H_2O$ (m.pt. 118°C).

- Limits of impurities; Ammonium. Not more than 50 parts per million (0.005%).
Arsenic (as As). Not more than 3 parts per million (0.0003%).
Heavy metals (as Pb). Not more than 10 parts per million (0.001%).
Sulphate. Not more than 200 parts per million (0.02%).

Functional use in foods. Colour-retention agent; firming agent.

b) Concentration properties (in part from C.R.C. Handbook of Chemistry and Physics).

Concentration (g/L) Anhydrous	Concentration (g/L) Hexahydrate	Molar concentration g-mol/L	Specific gravity at 20°C	Magnesium g/L
15.6	33.2	0.163	1.0126	3.982
22.2	47.4	0.233	1.0179	5.667
25.5	54.4	0.268	1.0205	6.509
30.7	65.5	0.322	1.0247	7.837
31.1	66.4	0.327	1.0250	7.939
35.9	76.6	0.377	1.0288	9.164

c) Cost: approx. $200 per 100kg; 13-14¢/L of 0.327M solution.

Appendix 2.

EVALUATION OF INDIVIDUAL CHARACTERISTICS OF OYSTER

AROMA CHARACTERISTICS	STRONG	WEAK	NOT PERCEIVED
Typical Oyster			
Fresh			
Aromatic			
Boiled-potato-like			
Bland			
Fishy			
Pungent			
Sour			

TASTE CHARACTERISTICS	STRONG	WEAK	NOT PERCEIVED
Typical Oyster			
Sweet			
Fresh			
Oily or Rich			
Salty			
Chicken-liver-like			
Boiled-potato-like			
Metallic			
Earthy			
Dry			
Fishy			
Bitter			
Sour			
Astringent			

TEXTURE CHARACTERISTICS	STRONG	WEAK	NOT PERCEIVED
Chewy			
Rubbery			
Fibrous			
Dry			
Gritty			

Appendix 3.

SENSORY EVALUATION OF OYSTER

SAMPLE:

PANELIST:

DATE:

OVERALL EVALUATION (PLEASE MARK, X)

N.B.: PLEASE EVALUATE INDIVIDUAL CHARACTERISTICS ON FOLLOWING PAGE PRIOR TO EVALUATION BELOW.

ACCEPTABILITY	AROMA	TASTE	TEXTURE	SCORE
__LIKE EXTREMELY	__LIKE EXTREMELY	__LIKE EXTREMELY	__LIKE EXTREMELY	9
__LIKE VERY MUCH	__LIKE VERY MUCH	__LIKE VERY MUCH	__LIKE VERY MUCH	8
__LIKE MODERATELY	__LIKE MODERATELY	__LIKE MODERATELY	__LIKE MODERATELY	7
__LIKE SLIGHTLY	__LIKE SLIGHTLY	__LIKE SLIGHTLY	__LIKE SLIGHTLY	6
__NEITHER LIKE NOR DISLIKE	__NEITHER LIKE NOR DISLIKE	__NEITHER LIKE NOR DISLIKE	__NEITHER LIKE NOR DISLIKE	5
__DISLIKE SLIGHTLY	__DISLIKE SLIGHTLY	__DISLIKE SLIGHTLY	__DISLIKE SLIGHTLY	4
__DISLIKE MODERATELY	__DISLIKE MODERATELY	__DISLIKE MODERATELY	__DISLIKE MODERATELY	3
__DISLIKE VERY MUCH	__DISLIKE VERY MUCH	__DISLIKE VERY MUCH	__DISLIKE VERY MUCH	2
__DISLIKE EXTREMELY	__DISLIKE EXTREMELY	__DISLIKE EXTREMELY	__DISLIKE EXTREMELY	1
COMMENTS:	COMMENTS:	COMMENTS:	COMMENTS:	

POOR

QUALITY

ORIGINAL